BLACK HOLES AND COSMOLOGY

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Abstract. I have written two papers arguing that the usual description of a black hole is misleading, and since the behaviour of space/time outside the black hole is not affected, that might seem to be at least one paper too many. The second paper looked at what meaning one might ascribe to the present tense when describing distant objects, and in particular, black holes, and to the implication of time running slow near massive bodies. In this paper I point out some possible cosmological implications.

1. A Newtonian singularity

It is commonly believed that the idea that there is a singularity at the centre of a black hole is a result predicted by general relativity. In fact, it is a result predicted by Newton's theory of gravity. Newton's theory of gravity predicts that the gravity at the surface of a star of constant density is proportional to the radius of the star, so whatever the initial density a large enough star will collapse to a point under its own gravity.

My argument is that General Relativity shows why this does not happen.

The Schwarzschild solution is the simplest description of space around a star. It assumes a static coordinate system and it assumes spherical symmetry about the star. With those assumptions we expect that everywhere on a sphere centred on a star there will be the same acceleration towards the centre of the sphere, the acceleration due to gravity.

I shall describe such a sphere using measurements that can be made on or near the sphere, so I won't (for example) assume the mass of the star, nor even that the gravity is in fact caused by a star. I choose a sphere, choose its circumference, and choose an acceleration due to gravity on the surface of the sphere.

The curvature of space/time has two effects that are best explained if we imagine a slightly smaller sphere inside and concentric with the first, so that there is (say) 100 metres between the two spheres.

(1) A clock on the smaller sphere will run slightly slower than a clock on the larger. This has been experimentally verified on earth: a clock at the top of a tower runs slightly faster than a clock at the bottom.

(2) The circumference of the inner sphere would be $100 \times (2\pi - \delta)$ metres smaller than that of the outer, so the circumference of the inner sphere is slightly larger than we might expect. The value δ is called the *lost angle*. This effect is partly responsible for the gravitational lensing of light.

If time runs at different rates in different places we must invent another sort of time that everyone can use. On earth, we have defined *UTC* (universal coordinated time). A UTC second will seem a little longer at the top of the tower than at the bottom. When talking about space/time, a moment of time is defined by the time coordinate, and I am going to talk about space at an instant of Schwarzschild time.

By choosing the acceleration due to gravity on a sphere we fix the rate at which time slows across the sphere, but to calculate the rate at which the gravitational acceleration changes across the sphere we need to know the value of the Einstein tensor at the sphere. We need, in effect, to know if we are starting to penetrate the star that is responsible for the gravity. If the Einstein tensor is zero, the star (if there is a star) is smaller than the sphere. With that assumption we find that as we go towards the centre of the spheres we reach a sphere where time has stopped. This sphere is the *stationary limit* and its radius is the *Schwarzschild radius* [1].

Time has stopped, but that does not mean that space has stopped. At the stationary limit, the lost angle is 2π,[2] Continue in a radial direction through empty space and you get further away from the supposed centre: you are not going towards a centre, you are going through a wormhole, an Einstein Rosen bridge. There is no centre and no star in this space. The fact that there is no star should not be a surprise since we did assume that that space was empty everywhere.

If we assume the gravity is caused by a star then the radius of the star must be larger than the Schwarzschild radius. In this case time still slows as you go nearer to the centre of the star, but it never quite stops: the lost angle inside the star starts to decrease with decreasing radius, becoming zero at the centre of the star.

That's not quite the whole story. We can slice up space/time differently. We can imagine that every sphere is collapsing under gravity, and make coordinate time keep pace with proper time on each sphere. If we take a late enough moment of time from this space/time you have a collapsing universe centred on a singularity, irrespective of the history.

1.1. **To summarise.** We started with a description of gravity such as we expect to find at a distance from a large star. We calculated the curvature of space using a stationary coordinate system, and found two possible causes for the gravity. One requires the Einstein tensor is non-zero at and inside the event horizon, the other has no Einstein tensor anywhere. The solutions are distinct: one is a collapsed star, the other is a wormhole. Neither can evolve into the other over time, but they both have the same ultimate end if we accept that space remains symmetrical, that space remains empty

[1] I said I would only use local measurements of a sphere, measurements that can be made on or near the sphere. Thus observant readers may reasonably object to my talking about the radius of the sphere, since the radius is not a local measurement. By 'radius' I mean the circumference of the sphere divided by 2π, which *is* a local measurement. This slightly misleading usage is usual when talking about the space around a star.

[2] Where the Einstein tensor is zero the lost angle on a sphere can be calculated from the behaviour of time across the sphere.

apart from whatever causes the curvature, and provided it is meaningful (in this instance) to talk about what happens after an infinite time.

1.2. **Loose ends.** I will discuss the interior of a black hole after talking a little about the universe as a whole. Before even that, I will mention that the *event horizon* is another surface that in Schwarzschild space coincides with the stationary limit. The stationary limit and the event horizon do not coincide for stationary black holes having spin or charge: for those, the event horizon is inside the stationary limit.

2. Cosmology

There are two principles that guided thinking about the universe once general relativity was accepted.

(1) *the cosmological principle*, which was originally taken to mean that on a large enough scale everywhere in the universe was similar to everywhere else and unchanging over time.

(2) *the principle of local action*, the assumption that causality can be explained locally. Newton was uncomfortable that his theory of gravity implied that the movement of one celestial body should be felt instantly by all the others. As electrical attraction started to be understood, that too seemed to imply instant 'action at a distance'. Relativity, then general relativity, seemed to resolve this difficulty. Mass and charge give rise to fields, and changes in the field propagate like waves on a pond.

Bell showed that quantum physics makes predictions that cannot be explained by local action, but on a large scale it seems a weakness in a theory that it should rely on arbitrary action at a distance.

Observations of the known universe sit a little uncomfortably with both these principles. The popular image of the big bang is that it starts at a point and expands first slowly then very rapidly in a period called inflation, then expands more slowly, with the rate of expansion slowing under the influence of gravity, and finally we now believe the rate of expansion is speeding up again. The 'start at a point and expand' idea is flawed, in as much as a point cannot expand into anything bigger. The initial 'point' explains nothing that occurs during the expansion, so we might as well say it starts 'very small'.

Next we must consider if the universe is finite or infinite. It is mathematically possible that the universe is finite and yet has no edge, much as a the surface of a sphere is finite but has no edge. I'm making the arbitrary assumption that the universe is not finite in that sense, so I'm assuming that the universe is infinite. But you cannot form an infinite universe by expanding a finite 'very small' volume. This means the universe must have started infinite if it is to be infinite after expanding for some time.

If the universe starts infinite but very dense, and expands as a whole, that implies the infinite space is synchronised. It is hard enough to believe that the known universe, a part of the universe 93 billion light years across, expands at the same rate everywhere, especially when the rate of expansion changes in ways we cannot explain. It is even harder to believe that changes in an infinite universe are similarly synchronised. I therefore retreat to the two original principles, that the evolution of space everywhere is driven by local conditions, and that at no time does any part of space have special properties that are not found at other places and times in space.

Initially Einstein attempted to respect the same two principles, but he envisaged a finite universe. He abandoned his so called *static universe* when the discovery of the cosmic microwave background supported the big bang theory.

I look again at Einstein's static universe, but assume the universe is infinite, and call it a *continuing* universe.

3. Ignore the elephant

I will defer addressing the big bang, the metaphorical elephant in Einstein's static universe, and start by noting how black holes dictate the evolution of the current universe. Gravity causes matter to combine, and though some stars may explode redistributing their mass, it seems (pace Hawking) that black holes can only grow. It seems that the galaxies will, over immense time, become simply enormous black holes which I shall call *black galaxies*. The inter galactic distances seem to be growing too fast for gravity to pull them back together, but in a continuing universe that means the galaxies are getting closer to other (possibly black) galaxies outside the visible universe. We know of nothing that can halt the consolidation of matter into ever fewer and ever larger black holes separated by ever larger distances.

3.1. **A coordinate system for a continuing universe.** The models of the universe based on Friedmann's equation describe the universe as a time orderable space in which the stars including black holes are dismissed as local irregularities whose effect is smoothed out over the universe. Only one of these models describes a universe that is both infinite and continuing. That universe consists of empty space, which might seem uninteresting. However, the Friedmann models consider the overall distribution of mass/energy: in the nominally empty universe the stars are local irregularities where there is positive mass/energy, and there are other parts where the local irregularity is negative mass energy.

A time orderable space can be described as a space that evolves over cosmic time. The space at an instant of cosmic time is a *time slice*. I make the extra assumption (as do Friedmann models) that the whole of space/time, meaning the whole of the universe for the whole of time, can be addressed by a single coordinate system.

A universe of empty space with local irregularities can be addressed by coordinates $\{t, x, y, z\}$ where $\{x, y, z\}$ addresses a time slice at cosmic time t. Cosmic time is orthogonal to every time slice: expressed in terms of the metric, $g_{tx} = g_{ty} = g_{tz} = 0$. All coordinates run from $-\infty$ to $+\infty$. Every point in space/time maps to one and only one coordinate point, and every coordinate point maps to one and only one point in space/time.

I measure coordinate time in cosmic seconds, and local time in proper seconds, so the ratio of the two at any point tells us how slowly or fast local time moves at some point in the model. In mathematical terms, g_{tt} approaches (but does not reach) zero at the edge of a black hole.

4. The evolution of a black hole

4.1. **Representations and misrepresentations.** Some books assert that an astronaut falling in to a large enough black hole would fall peacefully through the event horizon[3]. But the astronaut takes an eternity of Schwarzschild time to pass through the stationary limit, and long before that the black hole into which they are falling will merge with another black hole. The merger will take a small fraction of a second as measured on earth, and a microsecond (or far less) of the astronaut's proper time[4]. In this short time, two spheres of a few score kilometres in circumference will be deformed into a single sphere. Far from falling peacefully through the event horizon, the astronaut would encounter appallingly violent conditions before even reaching the event horizon.

There is a presumption by some that black holes are static, unchanging. They have been called 'frozen stars'[5]. When two black holes merge, the space they occupy is churned, but the space external to the resulting black hole settles very quickly back to spherical symmetry. This suggests that the space quickly becomes static, but that may be misleading: by what mechanism could the turmoil relax? We should consider the possibility that the space continues to evolve, much as waves in static space continue to evolve unless they are somehow damped.

The Schwarzschild analysis predicts that time in a black hole slows exponentially[6], implying that there is only a finite proper time spread out over an infinity of cosmic time. So even if the evolution of a black hole is violent in terms of proper time, can it be neglected because its proper time is finite? In the earlier years of Britgrav there were sometimes longer presentations of research done at the host university. In one such, about 2005 or so, a presentation showed that an isolated region of space could be rotated through 180 degrees relative to a distant horizon by the action of extreme waves in the Weyl tensor. I'm sorry to say I don't remember the date, or the name of the presenter or the paper[7]. The twisting of space inside a black hole suggests that mass falling towards the centre of the hole may be turned around by the changing curvature, slowing, even stopping or reversing the collapse. So although the rate of proper time in a black hole relative to cosmic time will be very slow, the total elapsed proper time in infinite elapsed cosmic time may yet also be infinite.

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[3] See for example or 'Gravitation' page 822, by Misner Thorn & Wheeler, or `https://www.ign.com/articles/humans-can-safely-fall-into-a-black-hole-this-one-way-physicists-say`.

[4] see, for example, `https://arxiv.org/pdf/1602.03837.pdf`: Observation of Gravitational Waves from a Binary Black Hole Merger.

[5] This name is associated with Russian scientists: see for example `https://news.ycombinator.com/item?id=7894491`.

[6] see Misner Thorn & Wheeler equations 31.3).

[7] I shall be very grateful if any reader can give me a reference to the paper.

4.2. **Could black holes explode to form a *subuniverse*?** Over time, as black holes merged, individual black holes would grow to be more massive, perhaps far more massive, than the current visible universe. Suppose the turmoil in such a black hole tipped it over into a white hole[8]. The resulting explosion might evolve much as our visible universe evolved after inflation. Initially the rate of expansion would slow under the influence of its own gravity, then the rate of expansion would start to increase as the gravity of the surrounding universe started to become significant. If intelligent beings evolved in the subuniverse they might well conclude as we have, that the entire universe was expanding and not just that part which was visible to them.

Inflation is postulated to explain why the visible universe is so uniform: the theory proposes that the exploding universe immediately after the big bang remained small for long enough to become uniform over a volume that then expanded enormously in the inflationary era, subsequently slowing to continue to expand at a more modest rate (I may be showing my lack of cosmic physics here). A black hole may have undergone enough turmoil to ensure that it is uniform in which case it is unnecessary to postulate an inflationary era. The black hole will start the transition to a subuniverse at a density which could perhaps be similar to the density of the known universe after inflation[9].

5. Conclusions

I offer this paper in yet another attempt to interest people in the unstudied physics of what is commonly called a black hole. The reader can think of my cosmological speculation as a serving suggestion, an attempt to grab attention.

The physics of a black hole will, I assume, need new mathematical techniques. We tend to think of things happening in space, in Wheeler's words: "Mass tells space-time how to curve, and space-time tells mass how to move.", but when two black holes merge they do so in almost zero local time. There is no time for mass to 'move' in space: it is space itself that deforms.

If we extend a timelike geodesic from the edge of a black hole through all the black hole mergers to a moment when it emerges in a new subuniverse, the elapsed cosmic time will be (I guess) trillions of years, but the length of the geodesic in units of proper time might be (again, I guess) as little as a year, or even an hour. Out in the open universe, time goes quickly and nothing much happens. Inside a black hole, time is almost stopped, but activity is beyond frantic. It may be that the evolution of a black hole is almost purely causal, purely the evolution of complicated waves in space/time.

[8] Roger Penrose's Singularity Theorum implies that a black hole cannot evolve into a white hole, but that theorum assumes the positive energy condition.

[9] A black hole of mass m has a Schwarzschild radius of $2m$ and so a volume greater than $32\pi m^3/3$ and a density less than $3/(12\pi m^2)$. If we know the density of the universe at the end of inflation, that would suggest the mass of our subuniverse.